Oxygen Transport Membranes - An Enabling Technology for Cost Effective CO2 Capture

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Presentation Outline

- Program Concept
- CO_2 Impact and Economic Advantages
- Overview of OTM technology
- Technical Status
- Technology Roadmap
- Summary

Program Concept

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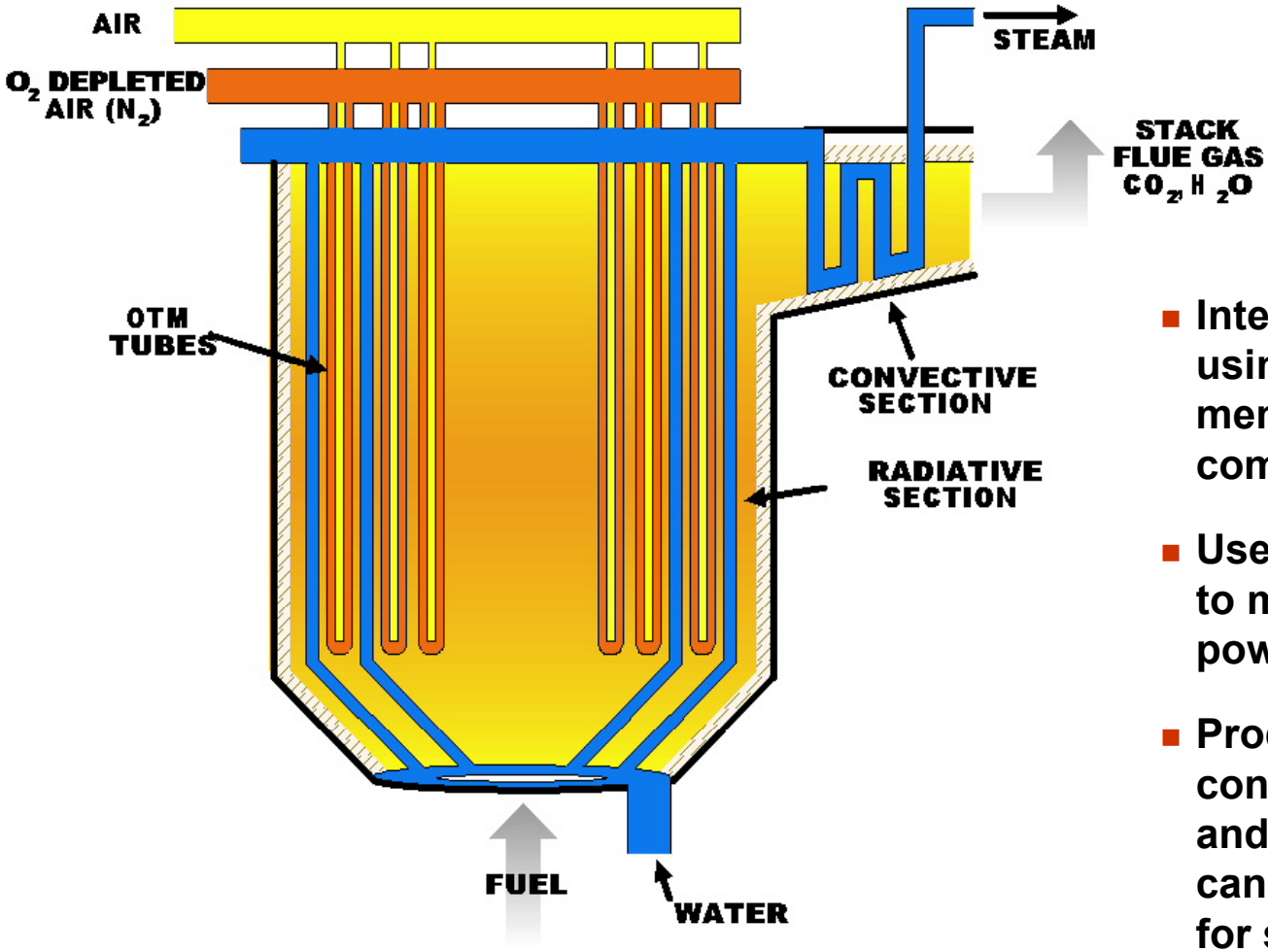
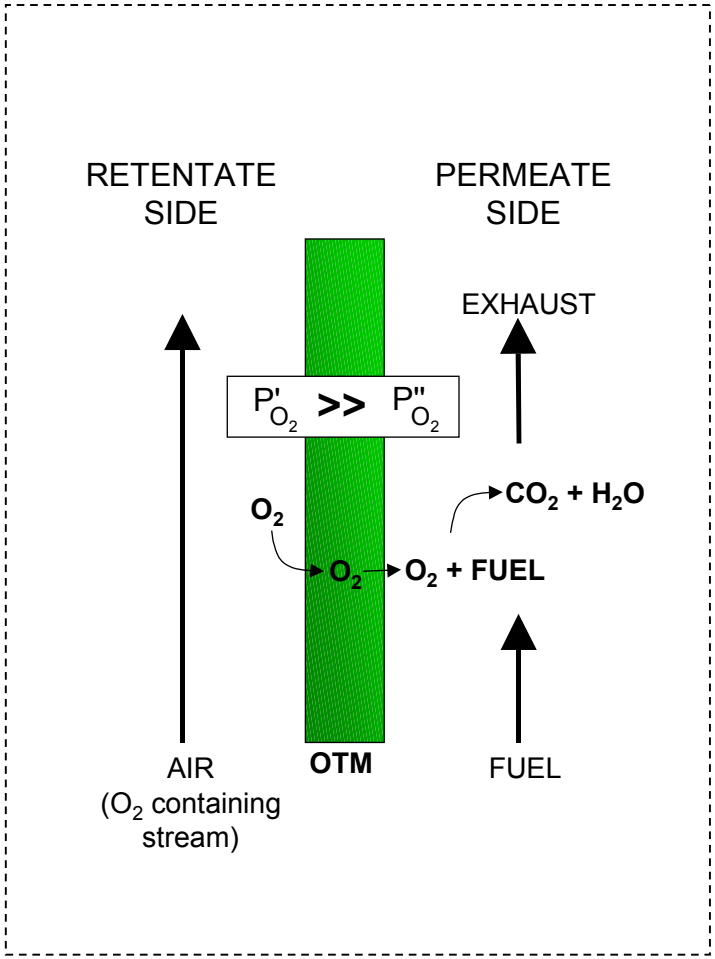
- **Oxy-fuel fired boiler**
  - simple exhaust compression for CO_2 recovery
  - improved thermal efficiency
  - low NO_x emissions
- **Oxygen source**
  - traditionally by external ASU
  - efficiency improvement overshadowed by high O_2 cost
- **Oxygen Transport Membranes (OTM)**
  - thermal integration of O_2 separation with the boiler
  - reduced operating and capital costs for oxy-fuel system

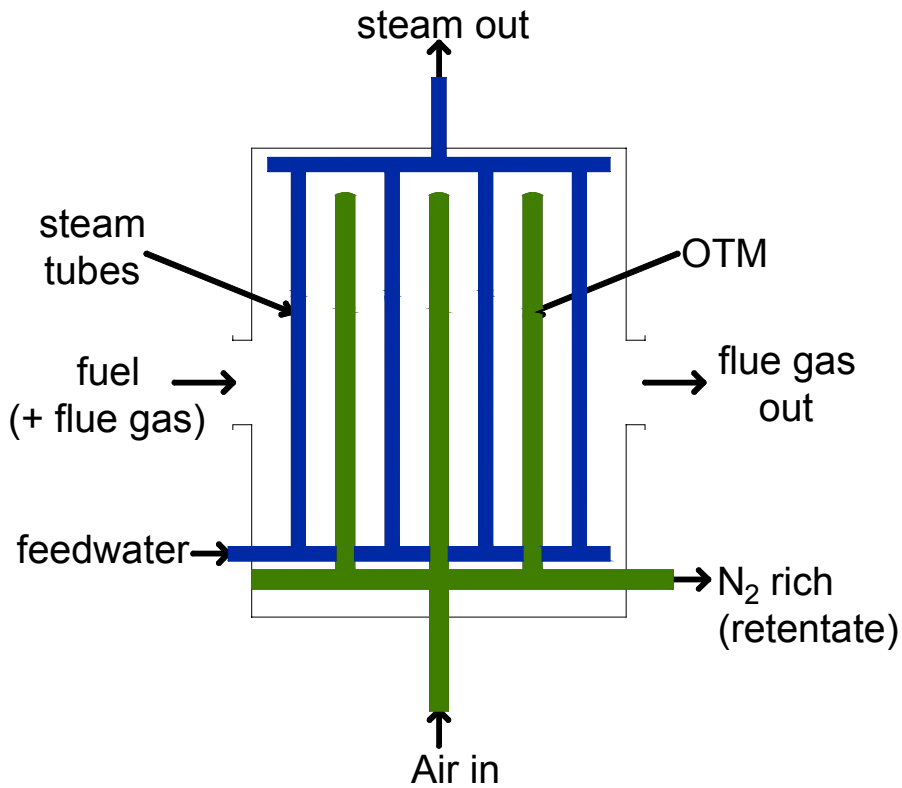
Praxair Advanced Boiler Concept



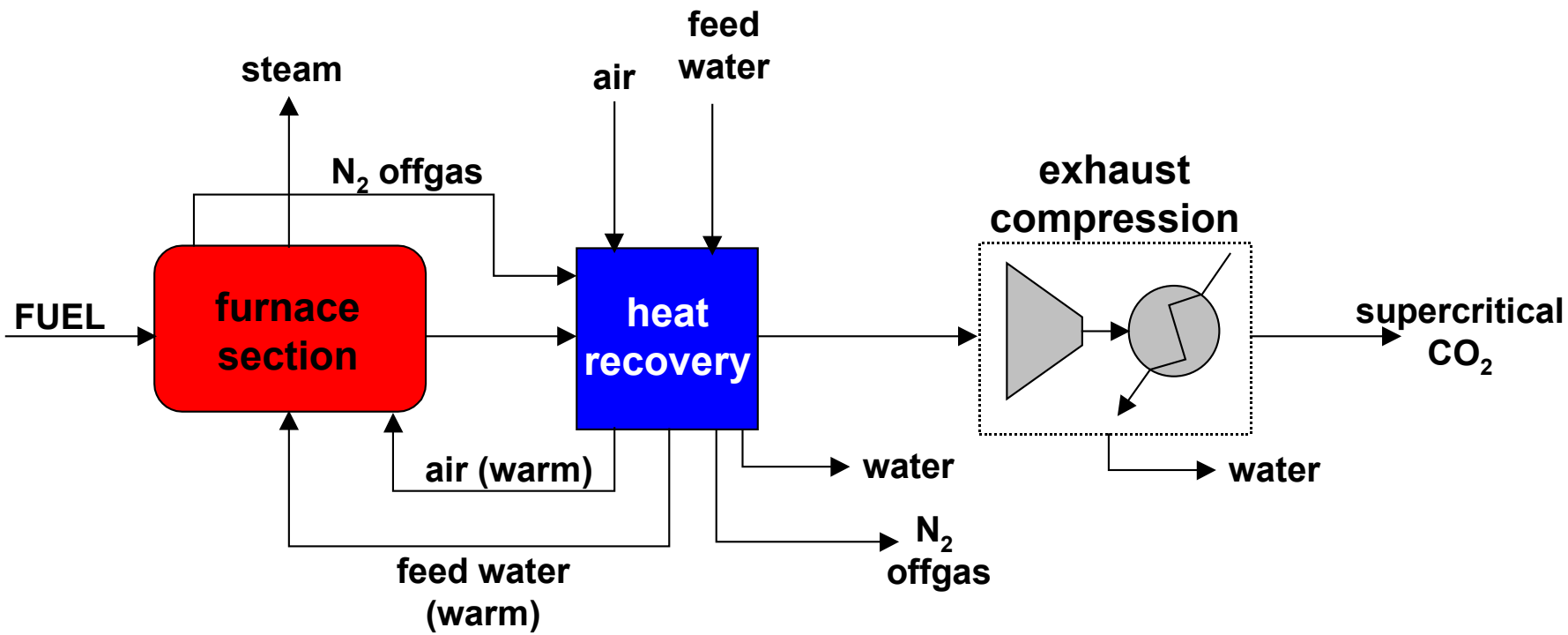
- Integrates air separation using oxygen transport membranes and combustion
- Uses chemical potential to minimize air separation power required
- Produces flue gas containing only CO_2, H_2O and inerts from fuel that can be readily cleaned up for sequestration.

OTM Reactive Purge Design





Conceptual OTM Boiler Process



OTM Boiler Concept

- OTM reduces air separation power by 90%
- High purity CO_2 exhaust reduces the cost of capture.
- Cost of carbon capture & compression $9-$16/ton.

CO_2 Impact and Economic Advantages

Economic Evaluation & CO_2 Impact Summary

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- **Fuel Savings**
  - **$600 million annually @ 20% conversion**
  - **14% reduction in CO_2 due to fuel savings alone**
  - **@ 60% boiler conversion, ~ 1% reduction in carbon emissions due to fuel savings**
- **Cost of Carbon capture and compression $9-16/ton**
- **@ 20% conversion of boiler market, with sequestration**
  - **19% CO_2 savings are achieved versus continuing current path**
  - **1.8% of total carbon emissions**
- **@ 100% conversion with sequestration**
  - **100% CO_2 savings are achieved versus continuing current path**
  - **10% of total carbon emissions**

Economics Case Study

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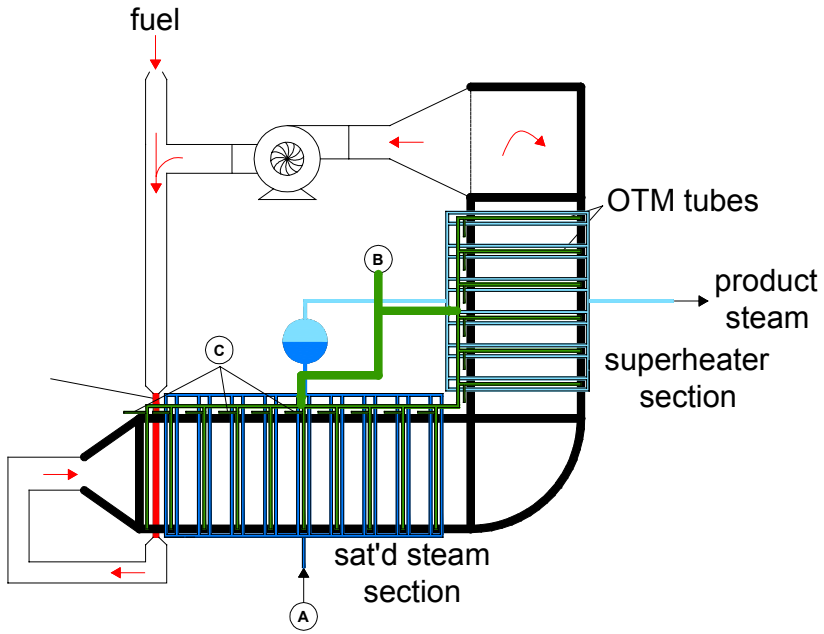
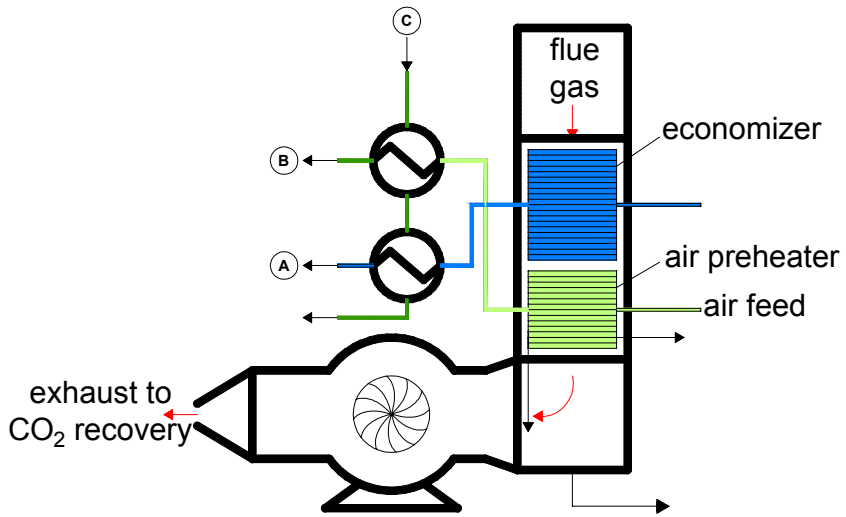
Assumptions:

- **500,000 lb/hr process steam**
- **natural gas fuel**
- **cross-flow configuration**
- **no air leakage**
- **~75% O_2 recovery**





Advanced Boiler - Economic Advantage

Costs	Conventional Boiler	Advanced OTM Boiler
System Costs		
Boiler	$6,000,000	$8,500,000
CO_2 capture system	$30,500,000	$6,000,000
Total Capital	$36,500,000	$14,500,000
Operating Costs		
Annual fuel cost @ $3.5/MM BTU ($0.0033/MJ)	$21,000,000	$19,700,000
Annual power cost @ $0.045/kWh	$53,000	$1,500,000
Operating cost savings with condensing heat exchanger	-	$(1,300,000)
Total boiler operating cost	$21,100,000	$19,900,000
CO_2 Capture Costs		
Annual steam @ $3.5/MM BTU	$4,100,000	
Annual power @ $0.04/kWh	$2,900,000	$1,500,000
Annual chemicals	$1,500,000	
Total CO_2 Capture Op. Cost	$8,500,000	$1,500,000

→ 60%

→ 6%

→ 80%

Advanced Boiler - Economic Advantage

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	Advanced Boiler NO CO_2 capture	Conventional Boiler w/ CO_2 capture	Advanced Boiler w/ CO_2 capture
CO_2 Reduction (ton/yr, based on natural gas)	20,700	330,000	330,000
Incremental annualized capital (12%, 20 year life)	$ 330,000	$ 4,080,000	$ 1,140,000
Incremental annual operating cost	$ (1,200,000)	$ 8,500,000	$ 300,000
$/ton CO_2 avoided		$ **38**	$ **4**
$/ton carbon avoided		$ **139**	$ **16**

OTM Technology and Technical Status

Reactive Applications - Features & Issues

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- Features
  - Large driving force
  - Severe Environment - Robust material required
  - Large O2 gradient causes compositional stress
  - Heat generation - Wall T control is critical
- Technology Issues
  - Strength of tubes
  - Managing compositional stress in tube
  - Control of wall Temp
  - Film integrity
  - Carbon formation
  - Reliability of metallic components at high T

Advanced Boiler Accomplishments to Date

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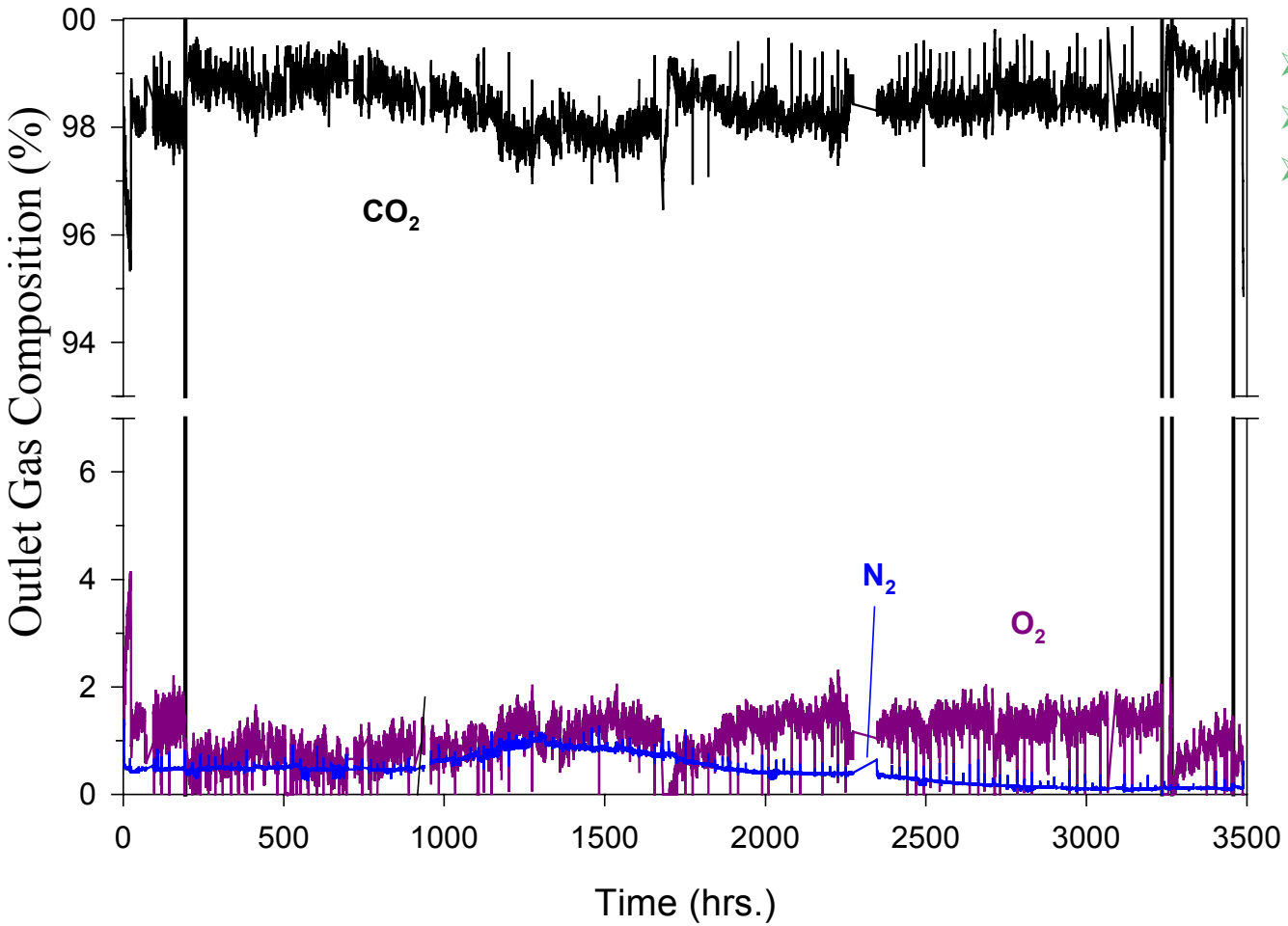
- Complete combustion of simulated fuel demonstrated
- Improved materials identified
- Boiler design concepts developed.
- Confirmed temperature control is possible at conceptual level.

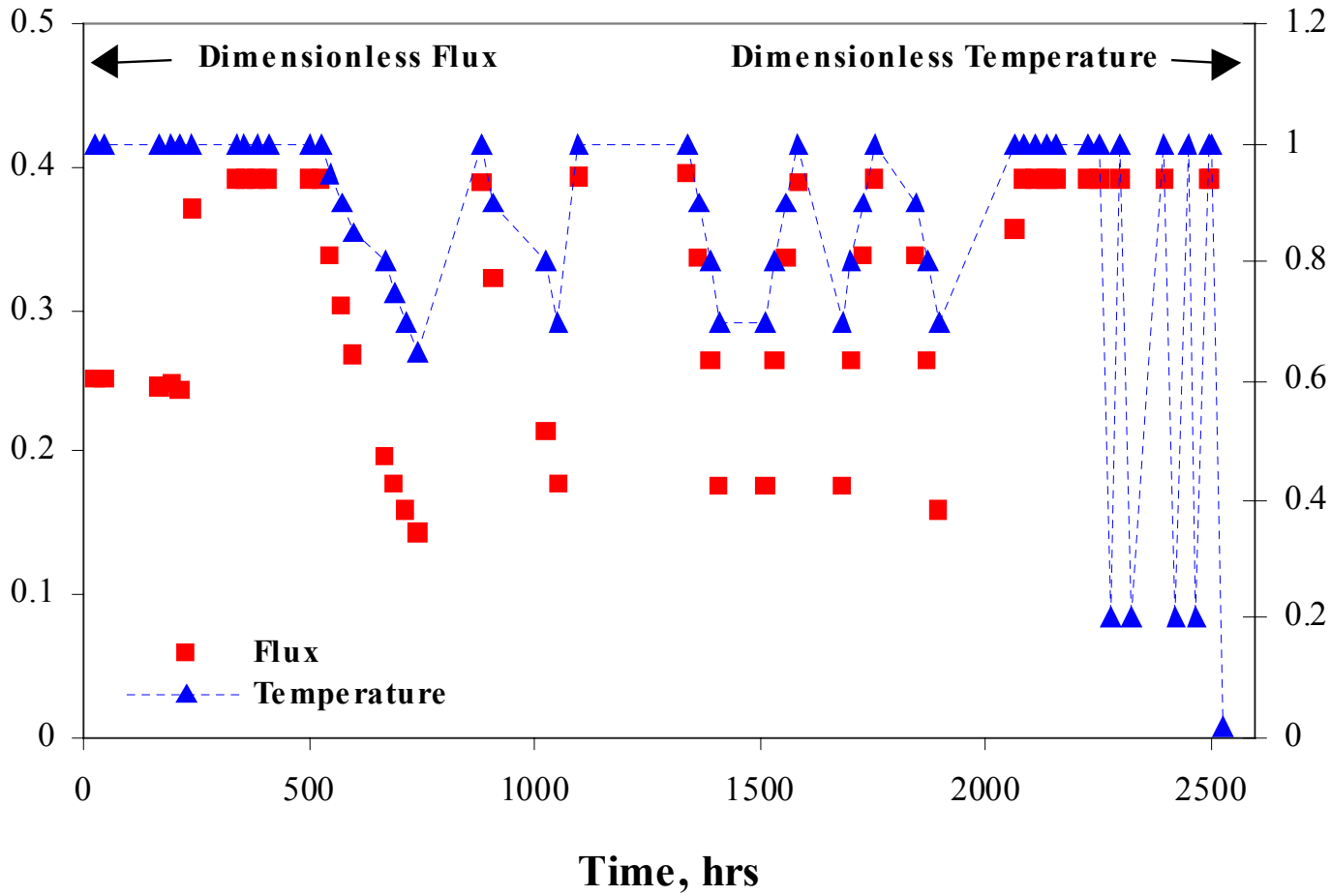
Combustion Testing



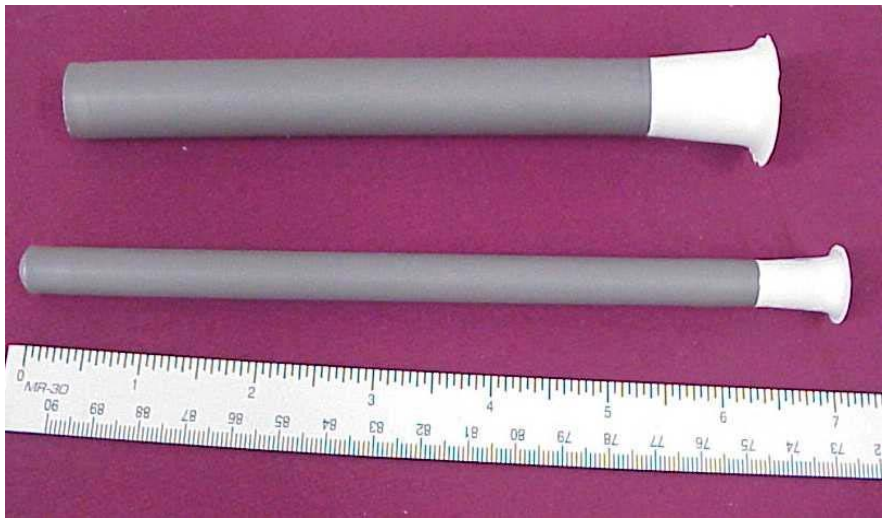
- 98-99% CO_2,
- 1-2% O_2,
- 0-1%N_2

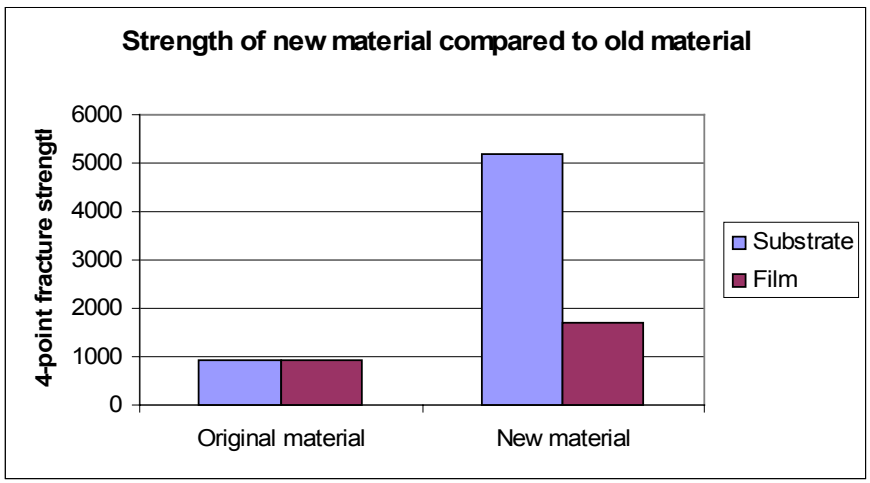
H_2 and CO below GC detection limit (10 ppm)

Life and Cycle Test of OTM Membrane



OTM Material Improvements





- Tubes cycled multiple times with no leaking
- Expansion properties improved
- Mechanical strength improved
- High oxygen fluxes achieved

OTM Manufacturing

- Manufacturing facilities in place to make commercial size tubes

Technology Roadmap

Advanced Boiler Technology Roadmap

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- **Phase 1 - Proof of Concept 2002 - 2006**
  - Develop combustion ceramic membrane technology
  - Develop and model conceptual designs to set technical targets, develop thermal management strategies and confirm economics.
  - Demonstrate membrane and combustion performance on a small multi-tube reactor
- **Phase 2 - Pilot 2006-2007**
  - Design, construct and operate a small advanced boiler to demonstrate membranes, heat transfer and CO_2 capture
  - Continue work on membrane life and thermal management issues.

Advanced Boiler Technology Roadmap (cont)

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- Phase 3 - Demonstration 2008 -2009
- Design, construct and operate a small commercial size (20 MMBtu/hr) advanced boiler to demonstrate membranes, heat transfer and CO_2 capture performance
  - Demonstrate/project economic viability of the technology
  - Develop technology to integrate with coal fired industrial boilers

Summary

Advanced Boiler Program Summary

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- Provides basis for a a fundamental shift in the supply of oxygen for combustion.
  - One tenth of the power required for cryogenic O2 production.
- Improved boiler efficiency reduces CO2 without sequestration and has ultra-low emissions.
- CO2 Capture and compression potentially as as low as $9/ton of carbon.
- Improved efficiency provides economic incentive for commercialization.

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End

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Thank You
Questions?